

Study of sub-barrier fusion of $^{36}\text{S}+^{50}\text{Ti}, ^{51}\text{V}$ systems

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Abstract. A detailed comparative study of the sub-barrier fusion of the two near-by systems $^{36}\text{S}+^{50}\text{Ti}, ^{51}\text{V}$ was performed at the National Laboratories of Legnaro (INFN). Aim of the experiment was the investigation of possible effects of the non-zero spin of the ground state of the ^{51}V nucleus on the sub-barrier excitation function, and in particular on the shape of the barrier distribution. The results show that the two measured excitation functions are very similar down to the level of 20 - 30 μb . The same is observed for the two barrier distributions. Coupled-channels calculations have been performed and are in good agreement with the experimental data. This result indicates that the low-lying levels in ^{51}V can be interpreted in the weak-coupling scheme, that is, $^{51}\text{V}(I) = ^{50}\text{Ti}(2^+) \otimes p(1f_{7/2})$.

1 Introduction

Most of the existing near- and sub-barrier fusion studies have concerned systems where both projectile and target are even-even nuclei. This is mainly due to the simpler theoretical treatment when both nuclei have 0^+ ground states. However, interesting effects are expected when odd spins are involved [1]. The ion-ion potential and consequently the height of the Coulomb barrier would be different for each magnetic substate. Thus, every m-substate has to be treated separately, and the coupled-channels (CC) equations solved accordingly. This may produce different fusion cross sections near the barrier and the shape of the barrier distribution should keep memory of the various barriers associated to the m-substates.

In this framework, at the National Laboratory of Legnaro (LNL) a detailed measurement of the fusion excitation functions for the two systems $^{36}\text{S}+^{50}\text{Ti}, ^{51}\text{V}$ has been performed, where no previous data were available. The nucleus ^{50}Ti is spherical and rather stiff because of its closed neutron shell. On the other hand, the ^{51}V nucleus has a large non-zero spin ($7/2^-$) in its ground state and

it is also essentially spherical because of its very small quadrupole moment [2].

The aim of the measurement was to identify differences in the fusion excitation function of the two cases, that may possibly be attributed to the non-zero spin ($7/2$) of the ^{51}V ground state. A different ion-ion potential and consequently a different barrier, is expected for each magnetic substate. Since the nuclei can be treated as spherical, possible effects of the finite spin of the ground state are isolated, without the onset of deformation. This allows to directly compare the two cases before performing detailed CC calculations. By comparing the two systems, we investigated if the shape of the barrier distribution keeps a trace of those different barriers.

2 Experimental procedure

The beam of ^{36}S was provided by the XTU Tandem accelerator of LNL in the energy range of 73 - 100 MeV and with an average intensity of 10 pA. The targets consisted of $50 \mu\text{g}/\text{cm}^2$ of ^{51}V and $^{50}\text{TiO}_2$ (90.3% enriched).

Fusion cross sections have been determined by direct detection of the fusion evaporation residues (ER) at small angles by separating out the beam and beam-like particles using the electrostatic beam deflector [3]. The ER were identified downstream of the deflector by a double Time-of-Flight (ToF) - ΔE - Energy telescope composed of two

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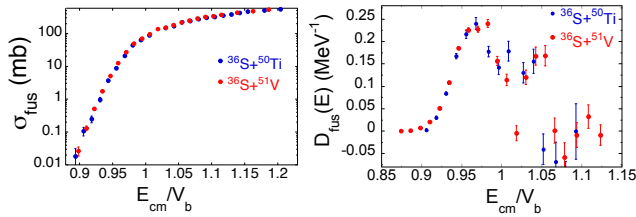


Figure 1. Comparison of the excitation functions (on the left) and barrier distributions (on the right) for the two fusion reactions. The energy scale is normalized to the heights of the two Coulomb barriers.

micro-channel plate time detectors (MCP) followed by a fast ionization chamber (Fast IC) [4] and by a silicon detector placed in the same gas (CH_4) volume of the Fast IC. Four silicon detectors were placed symmetrically around the beam direction at the same scattering angle to monitor the beam and to normalize the fusion yields to the Rutherford scattering cross section. Two ER angular distributions were measured at the energies of 80 and 90 MeV in the range from -6° to $+9^\circ$.

3 Results

3.1 Excitation function and barrier distributions

The cross sections were measured down to 20 and 30 μb for $^{36}\text{S}+^{50}\text{Ti}$ and $^{36}\text{S}+^{51}\text{V}$, respectively. The excitation functions of the two systems are compared in Fig. 1 (left panel), where the error bars are statistical uncertainties, that is, 1–2% at high energies and 20–30% at sub-barrier energies. The comparison showed a very similar behaviour of the two systems. Thus, in order to put in evidence possible small differences, a comparison of the barrier distributions was performed.

The barrier distributions were obtained using the three-point difference formula [5]. The energy intervals were of ~ 1.5 MeV in order to highlight the structures at energies above and below the barrier. The two barrier distributions are compared in Fig. 1 (right panel). Also in this case, the two shapes are extremely similar. Since no differences are observed between the two systems by the only comparison of the experimental data, a theoretical interpretation is necessary. In this perspective, a coupled-channels analysis was performed.

3.2 Coupled-Channels calculations

The coupled-channels calculations were performed by means of the CCFULL code [6]. The CC calculations for $^{36}\text{S}+^{50}\text{Ti}$ included the one-phonon excitation of both the lowest quadrupole vibrational state 2^+ at 1.554 MeV of ^{50}Ti and the first 2^+ state at 3.29 MeV of the ^{36}S . The case of $^{36}\text{S}+^{51}\text{V}$ was more tricky. The four magnetic substates $m = 1/2, 3/2, 5/2$ and $7/2$ of the $7/2^-$ ground state of ^{51}V produce different Coulomb barriers that have to be treated individually in the calculations. A modified version of CCFULL was therefore used in order to include the 2^+ excitation in ^{36}S as well as the couplings to the $5/2^-, 3/2^-, 11/2^-$,

$9/2^-$, and $3/2^-$ states in ^{51}V (for more details see [7]). Despite the slight inconsistency with the structure observed at energies above the main peak of both systems, as shown in Fig. 2 (bottom panels), the CC calculations reproduce very well the two similar excitation functions (Fig. 2 upper panels). This can be interpreted under the weak-coupling approximation, where the low-energy levels of ^{51}V result from the scheme $^{51}\text{V}(I) = ^{50}\text{Ti}(2^+) \otimes p(1f_{7/2})$ [8]. The relatively stiff ^{50}Ti (close to the double magic ^{48}Ca) is not significantly influenced by the additional proton to form ^{51}V .

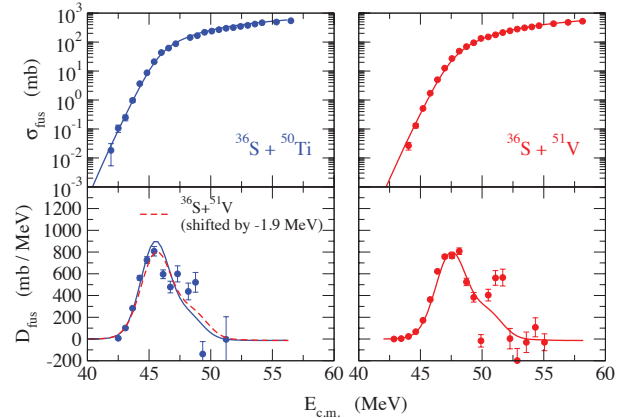


Figure 2. Excitation functions (top) and fusion barrier distributions (bottom) of $^{36}\text{S}+^{50}\text{Ti}$ (on the left) and $^{36}\text{S}+^{51}\text{V}$ (on the right), compared with the CC calculations described in the text.

4 Summary

The fusion cross sections of the two systems $^{36}\text{S}+^{50}\text{Ti}$, ^{51}V show a very similar behaviour down to 20–30 μb . A CC analysis was performed in order to highlight differences between the two systems attributable to the non-zero spin ground state of ^{51}V . The CC analysis included the low energy excitations of the ^{36}S and ^{50}Ti , ^{51}V nuclei and the results are in very good agreement with the experimental data of both systems. This may be explained in the weak-coupling scheme, where the extra proton in the $f_{7/2}$ shell of the ^{51}V does not significantly affect the sub-barrier fusion.

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